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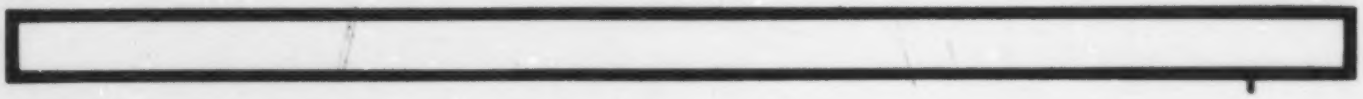

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LOW NO_x BURNERS FOR PULVERIZED-COAL-FIRED BOILERS IN JAPAN

by

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16. ABSTRACT: The paper describes nitrogen oxide (NOx) abatement by low-NOx burners (LNBs) and combustion modification (CM) for dry-bottom pulverized-coal-fired boilers in Japan. LNBs have been widely used in Japan as a simple way to reduce NOx emissions by 20-50%. NOx emissions can be reduced by more than 70%, using a LNB with CM; e.g., staged combustion or flue gas recirculation. NOx concentrations in flue gases from utility boilers have been reduced by LNBs and CM to 150-300 ppm with coal (dry bottom), 80-110 ppm with oil, and 20-60 ppm with gas. Based on improved technology, the NOx emission standard for coal-fired boilers (400 ppm for those constructed before 1983) was tightened in 1983 to 330 ppm for those constructed after 1983, and to 200 ppm for those to be constructed after 1987. LNBs may cost roughly 50% more than conventional burners. Yet, NOx abatement by a LNB and CM is much less costly than by flue gas treatment, primarily because of relatively low operating costs. Even when selective catalytic reduction (SCR) of NOx is applied for extensive NOx abatement, it is generally more economical to use a LNB and CM with SCR than to use only SCR. Possible problems with a LNB and CM for coal-fired boilers include increased unburned carbon, slag formation, and tube wastage.

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Nitrogen Oxides	Stationary Sources	07B
Coal	Japan	21D
Combustion Control	Low-NOx Burners	21B
Boilers	Combustion Modification	13A

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ABSTRACT

Low-NO_x burners (LNBs)* have been widely used in Japan as a simple way to reduce NO_x emissions by 20-50%. NO_x emissions can be reduced by more than 70%, using a LNB with combustion modification (CM); e.g., staged combustion or flue gas recirculation. NO_x concentrations in flue gases from utility boilers have been reduced by LNBs and CM to 150-300 ppm** with coal (dry bottom), 80-110 ppm with oil, and 20-60 ppm with gas. Based on improved technology, the NO_x emission standard for coal-fired boilers (400 ppm for those constructed before 1983) was tightened in 1983 to 330 ppm for those constructed after 1983, and to 200 ppm for those to be constructed after 1987.

LNBs may cost roughly 50% more than conventional burners. Yet, NO_x abatement by a LNB and CM is much less costly than by flue gas treatment, primarily because of relatively low operating costs. Even when selective catalytic reduction (SCR) of NO_x is applied for extensive NO_x abatement, it is generally more economical to use a LNB and CM with SCR than to use only SCR.

Possible problems with a LNB and CM for coal-fired boilers include increased unburned carbon, slag formation, and tube wastage. Countermeasures should be taken to solve the problems. For a wet-bottom boiler operated at higher temperature to fuse the ash, extensive NO_x abatement by a LNB and CM is not easily achieved. This paper will describe NO_x abatement by LNBs and CM for dry-bottom utility boilers.

PRINCIPLES OF NO_x ABATEMENT FOR PULVERIZED COAL BURNING

For pulverized coal combustion, the reduction of fuel NO_x is of particular importance because coal contains much larger amounts of nitrogen (1-3%) than does oil (0.1-0.5%) and produces a large amount of fuel NO_x, accounting for 70-80% of total NO_x. The fuel NO_x from coal consists of both volatile NO_x (derived from volatile nitrogen compounds in the coal) and char NO_x (derived from residual nitrogen compounds in the char). Usually the former is more predominant than the latter. The volatile NO_x can be abated efficiently by combustion control using a low-NO_x burner. Char NO_x is not controlled as easily, since it is less sensitive to injection design modifications in the early stages of combustion. Staged combustion (overfire air) is highly effective for NO_x abatement for pulverized coal because it reduces both fuel and thermal NO_x. However, flue gas recirculation (gas mixing) is not as effective because it reduces mainly thermal NO_x, which is not as much of a problem for coal-burning facilities.

A low-NO_x combustion model of pulverized coal by a LNB and staged combustion is shown in Figure 1. Usually 70-90% of total air for complete combustion is injected through the burner, with the rest through the overfire air port. In the primary combustion zone (I), volatile matter begins to burn, producing much NO_x due to the combustion of volatile nitrogen compounds.

*A glossary is provided at the end of this paper to assist readers who are unfamiliar with the abbreviations used here.

**All ppm values are at 6% O_2, dry basis.

In the secondary zone (II), the volatile matter continues to burn, the char begins to burn, and O_2 concentrations decrease, producing a reducing atmosphere that reduces NO_x to N_2. The reducing atmosphere also exists in the tertiary zone (III), where the NO_x concentrations reach a minimum just before the overfire air port for staged combustion. The CO concentration remains high. When the staged air (IV) is injected, the remaining char, CO, and other reducing gases are burned, resulting in a slight increase in NO_x concentration.

To minimize the NO_x level, the gas retention time in the reducing atmosphere should be as long as possible and the mixing of the secondary air with the flame formed by coal and primary air should be delayed. The resulting long flame with extended reducing zone, however, may promote slag formation and boiler tube wastage. The flame may be unstable, and unburned carbon may increase. Countermeasures for such problems should be taken. Otherwise, the NO_x reduction should be limited to where it does not cause an obvious problem.

Many LNBs have been developed to achieve a low NO_x level for various types of coal. Air ratios, coal injection velocity, flame swirling velocity, etc. are adjusted according to the nature of coal and the type of the boiler. Some LNBs use recirculated flue gas which is mixed with the secondary air or injected between the secondary air and the flame; this may increase NO_x abatement efficiency, but it increases the cost because of the required flue gas recirculation facility.

Examples of NO_x abatement by low-NO_x burners at coal-fired utility boilers are shown in Table 1.[1]

EPDC's TESTS ON LOW-NO_x COAL COMBUSTION[1,3]

The Electric Power Development Company (EPDC) has conducted extensive tests of combustion modification for NO_x abatement, jointly with major boiler manufacturers including Mitsubishi Heavy Industries (MHI), Babcock Hitachi, Ltd. (BHK), Ishikawajima-Harima Heavy Industries (IHI), and Kawasaki Heavy Industries (KHI). Some of the test results shown in Figure 2 indicate that, by using a combination of low-NO_x burners with staged combustion and flue gas recirculation, NO_x can be reduced by 60-80% (to 100-150 ppm with low-nitrogen coal and to 150-200 ppm with nitrogen-rich coal). A test conducted jointly with Company C indicated that flue gas recirculation was not effective for NO_x abatement with Coal E, and that unburned carbon increased considerably with the application of staged combustion.

NO_x ABATEMENT BY DF-CN BURNER AT ISOGO STATION, EPDC[2,3,4]

IHI and Foster Wheeler Energy Corporation of the U.S. have developed a low-NO_x burner called the IHI-FW DF-CN (Dual Flow Convergent Fuel Nozzle) burner. It is based on the following principles for NO_x reduction:

(1) Minimum primary/secondary mixing prior to completion of the combustion of the volatile fraction.

(2) Ignition stability at the injector.

(3) Dilution of the secondary air with self-recirculating combustion products.

The burner has been used at the Isogo Station of EPDC for two 265 MW coal-fired boilers of IHI-FW single drum type with natural circulation using domestic low-nitrogen coal (about 1.0% N), rich in volatile matter (about 40%). Since the station is located in Yokohama City with a population of about 4 million, increasingly stringent NO_x control has been asked by the city.

The boilers were completed in 1967 and 1969, and were modified in 1973 with an overfire air port system for NO_x abatement (Table 2). As a second step to meet the increasingly stringent NO_x regulation, an IHI-FW DF-CN burner and a boundary air system (Figure 3) were installed in 1977. The boundary air system prevents the melting of the ash. As a third step, eight additional overfire air ports were installed in 1979 near the side walls, and a division wall, based on the tests conducted by IHI. Thus NO_x was reduced to 170-190 ppm by opening the overfire air damper by about 40% (overfire air nearly 20%). In April 1980, further NO_x reduction to 159 ppm was asked by the city. The NO_x reduction has been attained by increasing the damper opening ratio. Tests on steam injection through oil-burner guns indicated a little NO_x reduction at a small damper opening ratio (Figure 4).

DRB AND PG DUAL BURNER AT TAKEHARA STATION OF EPDC[3,5,6]

The Takehara Station has two coal-fired boilers -- No. 1 (250 MW) and No. 3 (700 MW) -- both of Babcock & Wilcox type constructed by BHK. A dual-air-register burner (DRB) developed by Babcock & Wilcox, U.S.A., is used for boiler No. 1, and a primary gas (PG) dual burner is used for boiler No. 3. The PG dual burner is based on the dual-air-register burner with improvements by BHK. The major improvement is that the PG dual burner has a primary gas port for injection of recirculated flue gas between the secondary air and the flame formed by coal and the primary air.

Figure 5 shows the relationship between the heat release rate at the burner zone and NO_x concentrations with three types of burners -- conventional circular-air register, dual-air register, and PG dual burner with or without two-stage combustion and gas mixing. Boiler No. 1 uses a dual-air-register burner and produces about 200 ppm NO_x using two-stage combustion, and about 300-360 ppm NO_x without two-stage combustion. A test furnace with a higher heat release rate produced about 400 ppm NO_x with the dual-air-register burner and around 350 ppm NO_x with the PG-dual burner when staged combustion was not applied; it produced 100-200 ppm NO_x with the PG dual burner with two-stage combustion and gas mixing.

Boiler No. 3, with a heat release rate between that of Boiler No. 1 and the test furnace, may be able to give a NO_x concentration of about 150 ppm. Actually, NO_x from Boiler No. 3 has been kept at 250-300 ppm because the flue gas is further treated by selective catalytic reduction to reduce NO_x to about 60 ppm.

SGR BURNER AND PM BURNER[3,7,8]

MHI has developed a separate-gas recirculation (SGR) burner which is used at EPDC's Matsushima Station for two 500 MW boilers. The burner is based on two principles that MHI has found to be important for NO_x abatement:

(1) The temperature in the volatile matter combustion zone should be kept as high as possible, and combustibles should stay in this zone as long as practicable.

(2) The temperature of the char combustion zone should be appropriately low, and combustion should be completed in this zone.

The burner injects recirculated flue gas between secondary air and the flame formed by coal and primary air. A flame holder is at the outlet of the coal nozzle, maintains stable ignition, and expedites the combustion of volatile matter. NO_x concentrations in flue gases from the tangential-firing 500 MW boilers have been maintained at 200-280 ppm with imported coals.

For further NO_x abatement, MHI has developed the Pollution Minimum (PM) burner which gives a fuel-rich flame and a fuel-lean flame with recirculated flue gas injected in between to conduct off-stoichiometric combustion efficiently. Figure 6 shows the relation between NO_x concentrations and the primary air/coal ratio in kg/kg. A ratio of about 3-4 corresponds to the theoretical air for volatile matter in coal. NO_x concentrations are lowered with the smaller ratio because of the deficiency of O_2. On the other hand, the ratio 7-8 corresponds to theoretical air for coal. With the ratio of between 3-4 and 7-8, fixed carbon in coal burns with deficient O_2 to form NO_x.

A conventional burner -- C_o -- may produce a primary air/coal ratio of 2-3 as shown in Figure 6. If the primary air/coal supply is divided into two streams with different ratios -- C_1 for a coal-rich concentrated nozzle and C_2 for coal-lean weak nozzle -- for separate burning, the average NO_x value should be $(NO_x)PM$ as shown in Figure 6. This is the weighted mean of $(NO_x)C_1$ and $(NO_x)C_2$ and is substantially lower than $(NO_x)C_o$. The combined use of the concentrated and weak flames may result in low-NO_x combustion.

Figure 7 compares the NO_x concentrations for a Combustion Engineering (CE) conventional burner, SGR burner, and PM burner when used for tangential-firing commercial boilers and the test furnace. Since NO_x concentrations for test boilers agree well with those for commercial boilers, it is expected that, with use of a commercial PM burner, NO_x concentrations may be reduced to 60-80 ppm with Japanese coals and 100-150 ppm with imported coals.

The PM burner has been applied since late 1982 to an industrial boiler of Daishowa Paper Co. using Australian coal. By increasing overfire air from 5 to 17%, NO_x concentration decreased from 210 to 150 ppm with little increase of unburned carbon -- from about 4 to 4.5%.[9]

VD BURNER[10]

KHI has developed a low-NO_x burner called vortex diffuse (VD) burner which is used at the Sunagawa Station of Hokkaido Electric (Table 1). The burner is designed to reduce NO_x efficiently when added with overfire air and to prevent the increase of unburned carbon. The swirl vane in the primary throat has a relatively large angle to ensure flame holding and to effect broad distribution of pulverized coal in the furnace, so as to increase the combustion efficiency. Secondary and tertiary air is introduced to provide slow mixing with the coal and the primary combustion products by the deviation effect of the flame holder. Recirculated flue gas can be mixed with the secondary and tertiary air for further NO_x abatement. By the VD burner with 25% overfire air, NO_x has been reduced to 160-170 ppm with domestic coal low in nitrogen and rich in volatile matter similar to that used at the Isogo Station of EPDC.

CONCLUSIONS

Development of low-NO_x burners and firing systems in Japan has led to commercial application of techniques to significantly reduce NO_x emissions over uncontrolled levels. With the research currently underway, further reduction of NO_x emissions and improvements in the cost-effectiveness of NO_x control are anticipated.

NOTE: Dr. Jumpei Ando was supported by U.S. EPA Contract No. 68-02-3949 in the preparation of this paper.

GLOSSARY

BHK	Babcock Hitachi, Ltd.
CE	Combustion Engineering
CM	Combustion modification
DF-CN	Dual-flow convergent fuel nozzle burner
DRB	Dual-air-register burner
EPDC	Electric Power Development Company
FGR	Flue Gas Recirculation
FW	Foster Wheeler
GM	Gas-mixing to secondary air
IHI	Ishikawajima-Harima Heavy Industries
KHI	Kawasaki Heavy Industries
LNB	Low-NO_x burner
MHI	Mitsubishi Heavy Industries
NO_x	Nitrogen oxides
OAP	Overfire air port
OFA	Overfire air
PG	Primary gas
PM	Pollution minimum burner
SCR	Selective catalytic reduction
SGR	Separate-gas recirculation burner
TSC	Two-stage combustion
VD	Vortex diffuse
VM	Volatile matter

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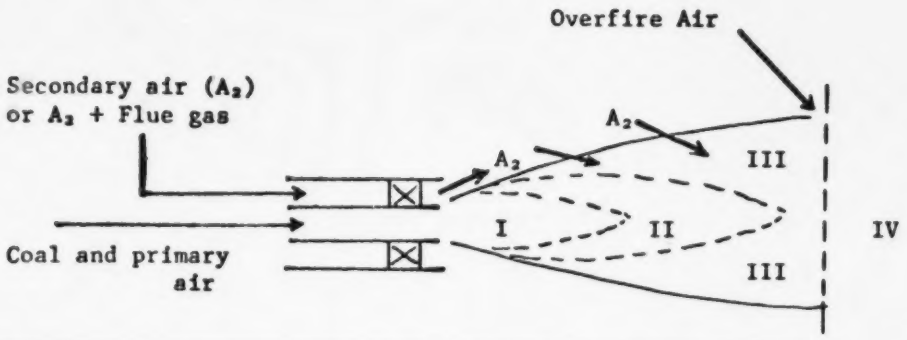


Zone	Burning Matter	NO_x Concentration
I	Most of volatile matter	High
II	Remaining volatile matter Part of char	Lowered (reducing atmosphere)
III	Char	Minimized (reducing atmosphere)
IV	Remaining char Reducing gas (CO, etc.)	Increased (oxidizing atmosphere)

Figure 1. Model of Low-NO_x Coal Burning.

TABLE 1. EXAMPLES OF COMBUSTION MODIFICATION FOR COAL-FIRED UTILITY BOILERS

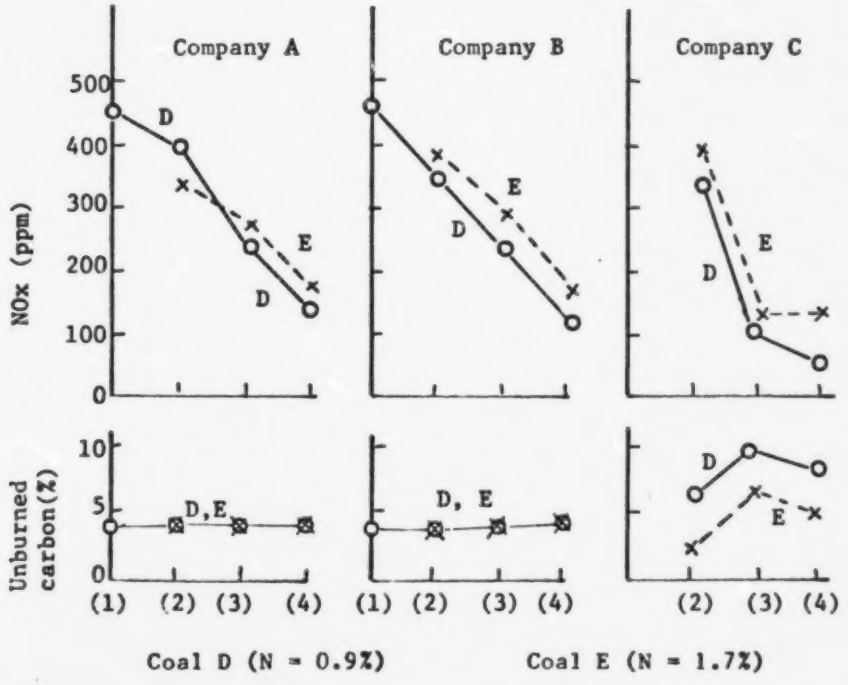
Station (Company)	Boiler (MW)	Coal Source	Burner Type	NO_x (ppm)
Isogo (EPDC)	265[a]	Domestic[b]	DF-CN[c]	150-200
Tomato-Atsuma (Hokkaido)	350[d]	Domestic[b]	DRB[e]	200
Matsushima (EPDC)	500[d]	Imported	SGR[f]	200-280
Sunagawa (Hokkaido)	125[d]	Domestic[b]	VD[g]	160-170

[a]Staged combustion is used.
[b]Low N, high volatile.
[c]Dual flow convergent fuel nozzle burner.(2)
[d]Staged combustion and flue gas recirculation are used.
[e]Dual-air-register burner.
[f]Separate-gas recirculation burner.
[g]Vortex diffuse burner.

TABLE 2. MODIFICATIONS MADE FOR INCREASED NO_x CONTROL AT THE ISOGO POWER UNIT

Month, Year	NO_x Emission Level by Regulation (ppm)[a]	Achieved NO_x Level (ppm)	Modifications
Before May, 1973	600	570	None
June, 1973	600	380 - 510	Two-stage combustion
April, 1977	480	240 - 250	Low-NO_x burner, curtain air
April, 1979	400	170 - 190	More rigorous two-stage combustion

[a]By Central Government



(1) Conventional Burner
(2) Low-NO_x Burner (LNB)
(3) LNB + Overfire Air (OFA)
(4) LNB + OFA + Flue Gas Recirculation

Figure 2. Examples of Combustion Modification Tests Conducted by EPDC and Boiler Manufacturers.

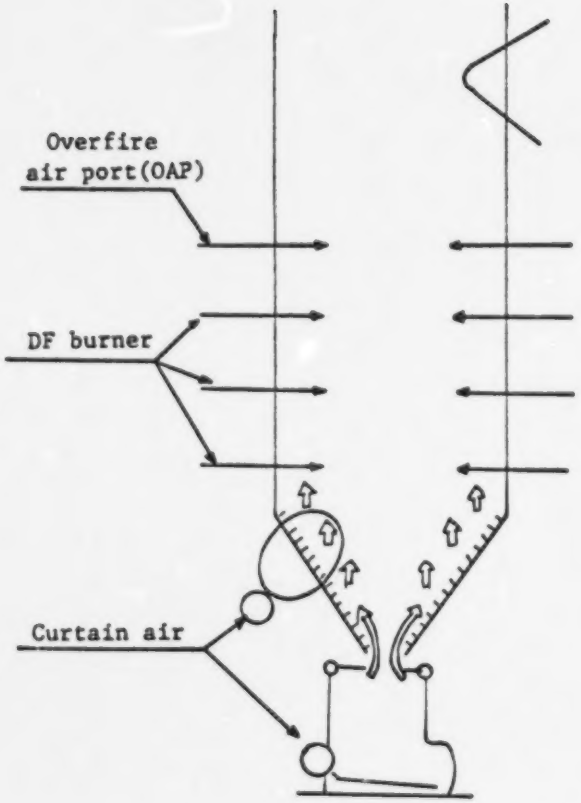


Figure 3. IHI's Boundary Air System.

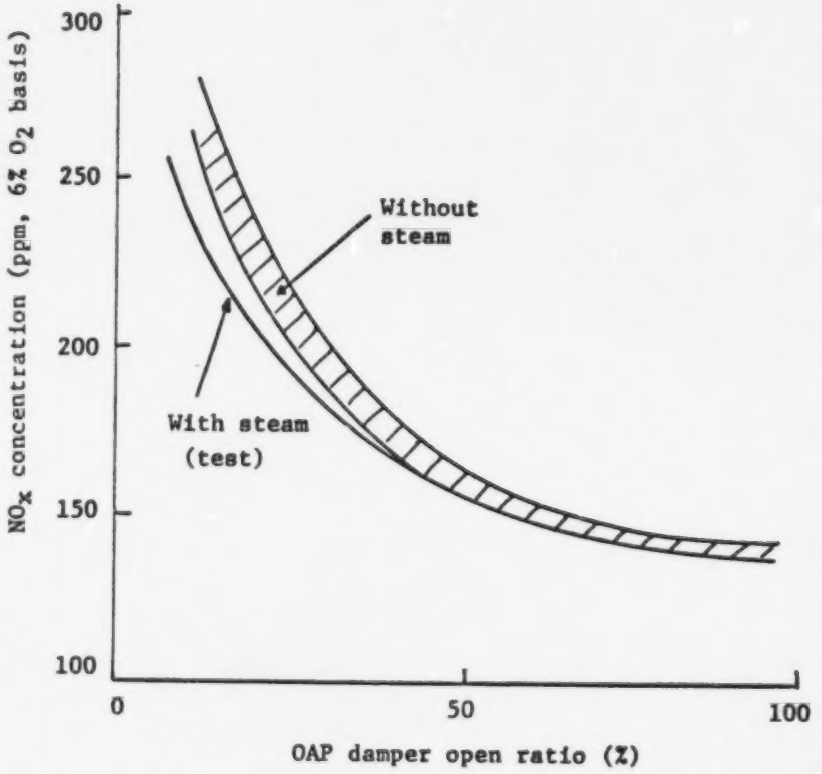
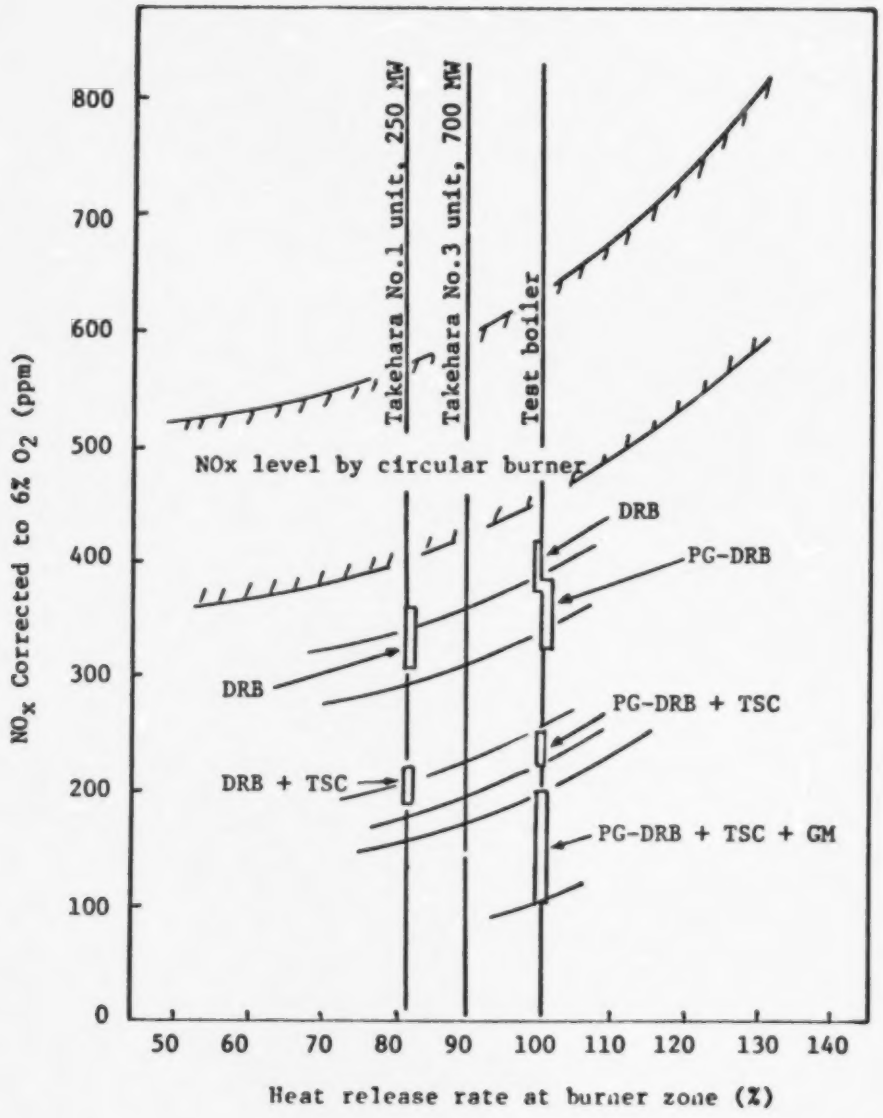


Figure 4. Damper Open Ratio and NO_x Concentration (Isogo).



DRB: Dual air register burner

PG-DRB: Primary gas type DRB

TSC: Two stage combustion

GM: Gas mixing to secondary air

Figure 5. Heat Release Rate at Boiler Zone.

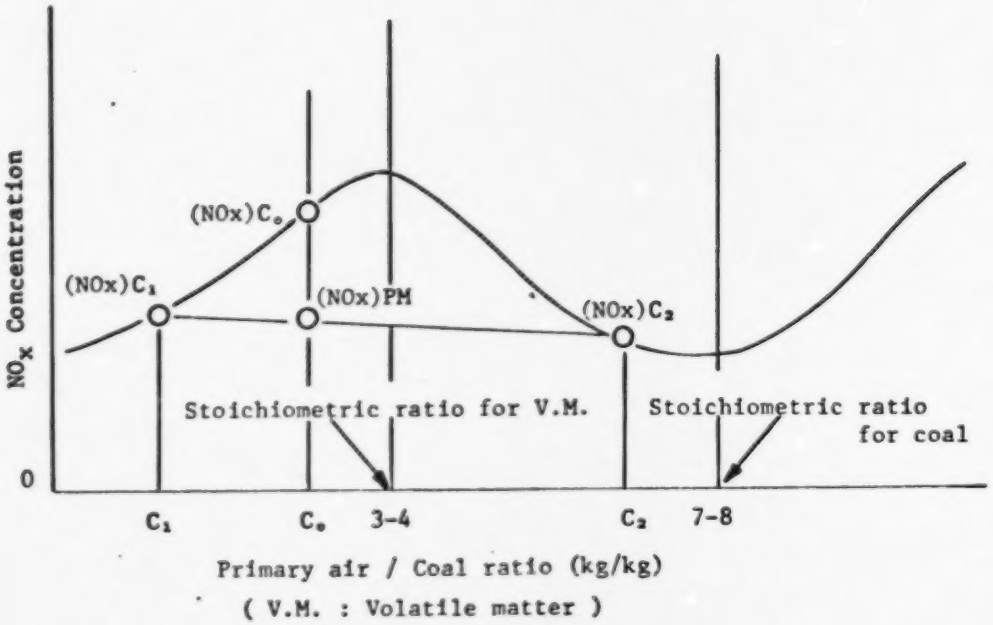


Figure 6. Concept of Pulverized-Coal-Fired Low-NO_x PM Burner.

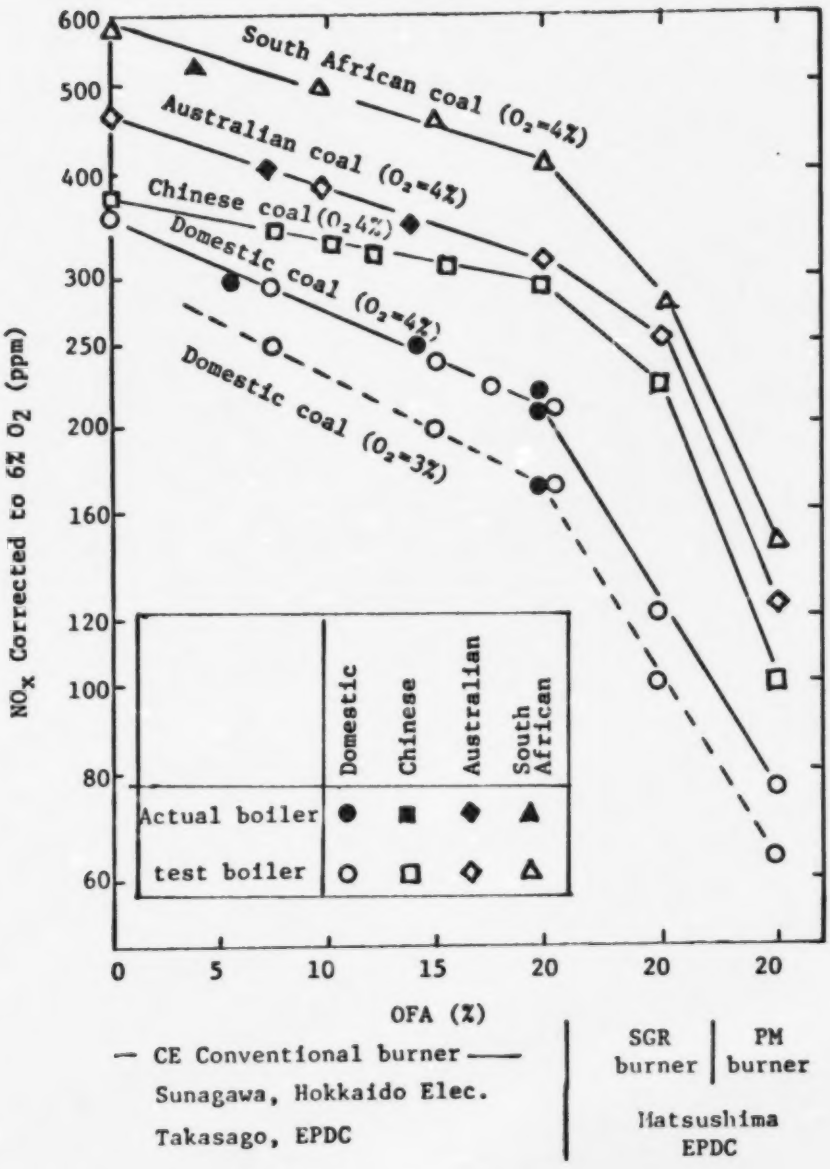


Figure 7. Comparison of NO_x Emissions: Laboratory Test Results vs Field Data